TECHNICAL REPORT 061

Interpretation of Habitat Quality from Air Photos at Marbled Murrelet Nest Sites in Mussel Inlet on the British Columbia Central Coast

2011

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F.L. Waterhouse, A. Donaldson,
P.K. Ott, and G. Kaiser

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Library and Archives Canada Cataloguing in Publication Data

Interpretation of habitat quality from air photos at Marbled Murrelet nest sites in Mussel Inlet on the British Columbia Central Coast / [prepared by E.L. Waterhouse ... [et al.]]

(Technical report ; 061)
Includes bibliographical references.
Available also on the Internet.
ISBN 978-0-7726-6481-5 (print version)
ISBN 978-0-7726-6483-9 (PDF)

1. Marbled murrelet--Habitat--British Columbia--Central Coast--Classification. 2. Marbled murrelet--Nests--British Columbia--Central Coast--Classification. 3. Forest canopies--British Columbia--Central Coast. 4. Aerial photography in forestry--British Columbia--Central Coast. 5. Aerial surveys in forestry--British Columbia--Central Coast. I. Waterhouse, F. M. Louise (Frances M. Louise), 1964- II. British Columbia. Forest Science Program III. Series: Technical report (British Columbia. Forest Science Program) 061

QL696 C42 I48 2011 333.95'833 C2011-909030-9

Citation

Waterhouse, F. L., A. Donaldson, P. K. Ott, and G. Kaiser. 2011. Interpretation of habitat quality from air photos at Marbled Murrelet nest sites in Mussel Inlet on the British Columbia Central Coast. B.C. Min. For., Mines Lands, Victoria, B.C. Tech. Rep. 061. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr061.htm

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Copies of this report can be obtained from:
Crown Publications, Queen's Printer
PO Box 9452 Stn Prov Govt
563 Superior Street, 2nd Flr
Victoria, BC V8W 9V7
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www.crownpub.bc.ca

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EXECUTIVE SUMMARY

We used newer, larger-scale 2007 colour air photos to interpret habitat attributes and classify habitat quality of 14 Marbled Murrelet (*Brachyramphus marmoratus*) nest sites identified in 1992 ($n = 2$) and 1999 ($n = 12$) in Mussel Inlet on the Central Coast of British Columbia. Mussel Inlet is a fjordland environment atypical of other areas for which the air photo interpretation classification has been tested using nest sites (i.e., Haida Gwaii, Vancouver Island, and south coastal British Columbia). Nesting habitat described by 3-ha plots centred on the nest site was characterized in Mussel Inlet as having complex canopies with large trees in mid to low meso slope positions, and as such is comparable to that reported elsewhere in British Columbia. However, comparisons of the nest plot habitat attributes to those at 27 random plots also suggested that interpretations of murrelet habitat selectivity for Mussel Inlet differed from other coastal areas due to differences in characteristics and availability of forest structures. Overall in Mussel Inlet, more nest plots were classed as lower quality (i.e., 50% Low and Very Low) on air photos compared to other British Columbian studies (i.e., ~14% Low and Very Low). Although selectivity testing based on air photo habitat class was inconclusive, particularly for the High and Very High quality habitats for which limited habitat was available (~1 % of the study area), a trend was indicated for higher proportional use of Moderate and Low habitats and lower proportional use of Very Low habitats. We discuss limitations of the samples used for this study and issues in interpretation, resolution, and scale in applying the air photo methods in topographically complex, fjordland landscapes such as Mussel Inlet. Given these limitations and issues, we recommend use of aerial survey methods to confirm occurrence of nest platforms.

ACKNOWLEDGEMENTS

We thank the following individuals for providing the nest locations analyzed in this study: 1992 sites from Dale Seip, B.C. Ministry of Forests and Range; Lynn Pretash and Rick Burns, Consultants; Jean-Pierre Savard, Environment Canada; 1999 sites from Glen Keddie, Consultant; Gary Kaiser, Environment Canada through grants to Fred Cooke, Chair in Wildlife Ecology at Simon Fraser University. Todd Davis, geospatial analyst, B.C. Ministry of Forests and Range, provided GIS support for the project. Ann Donaldson interpreted the nest locations for this study and provided the comparisons to the 2008 habitat map produced for the B.C. Ministry of Environment. Biometric support was provided by Peter K. Ott. External reviews were provided by Alan E. Burger, University of Victoria; Doug Steventon, B.C. Ministry of Forests and Range; Dale Seip, B.C. Ministry of Environment; and Douglas Bertram, Environment Canada. Funding for this analysis of the original data was provided by the B.C. Ministry of Forests and Range.

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Standards for using air photos to classify forest for its potential as nesting habitat for Marbled Murrelets (*Brachyramphus marmoratus*) were introduced in 2004 (Donaldson 2004; Burger et al. 2009). The Marbled Murrelet, a seabird, usually nests on large, mossy branches in older forests (Burger 2002). Habitat quality of forest is ranked from Nil (non-forested) to Very High on air photos using a 6-class qualitative classification (Burger 2004). Higher-quality habitats have more abundant key habitat features, such as large trees, large limbs or mossy pads, and complex canopies, and are thus thought to have greater potential for supporting nest platforms and access for the bird into the stand (Canadian Marbled Murrelet Recovery Team 2003). Several studies have examined the effectiveness of the air photo interpretation classification by using samples of nest sites from south coastal British Columbia (Sunshine Coast and the west coast of Vancouver Island) and Haida Gwaii (Waterhouse et al. 2002, 2004, 2007, 2008, 2010). Generally, these studies support selectivity by murrelets for higher-quality habitats, as classified by the air photo method, within forests >140 years old (discussed by Burger and Waterhouse 2009). The estimated ranges and distributions of habitat attributes considered during air photo habitat assessments were collated for coastal British Columbia by Waterhouse et al. (2004) using sites associated with murrelet activity, including nest sites. This study included a small subset of nest sites from Mussel Inlet on the central mainland coast (Kaiser and Keddie 1999); however, the interpretation of the Mussel Inlet nest sites for habitat quality was limited due to poorer quality of the older 1:40 000 black and white air photos. We report new habitat assessments of the Mussel Inlet nest sites using newer, larger-scale air photos.

Confirming the application and fit of the air photo habitat classification on the British Columbia central mainland coast is important because habitats used by Marbled Murrelets may change with latitude, and in British Columbia few nest sites are known outside of the southern areas. Latitude influences the availability, structure, and productivity of forests and the factors that affect habitat suitability for murrelets—for example, elevation of habitat and tree height (Burger 2002; Canadian Marbled Murrelet Recovery Team 2003; Burger et al. 2010). Furthermore, abundance of murrelets increases towards northern latitudes, with the core population occurring in Alaska (Piatt et al. 2007). The Central Coast of British Columbia is identified by the Canadian Marbled Murrelet Recovery Team (2003) as a separate management region for the Marbled Murrelet. This region coincides with an area identified by the British Columbia government for ecosystem-based management (EBM) (British Columbia Integrated Land Management Bureau 2009a), for which the Marbled Murrelet is considered a management focal species (Horn et al. 2009). In order to assist EBM planning, a map of murrelet nesting habitat, hereafter referred to as the 2008 habitat map, was produced by applying the air photo standards across the region using either digital or colour 1:15 000 scale air photos primarily from 2006 to 2007 (Donaldson and Smart 2009a, 2009b). The entire landscape, regardless of elevation, was assessed to delineate habitat polygons, including all alpine and non-forest, on original forest cover. The availability of the newer air photography and the 2008 habitat map provides an opportunity to re-analyze the Mussel Inlet nest site locations and test for murrelet habitat selectivity in this area.

Our objectives for this study were to:

1. determine if murrelets select for specific nest habitats, as described by the air photo standards, within the >140-year-old forest (hereafter referred to as the mature/old forest) at Mussel Inlet. We focussed on this age-class because it is generally associated with murrelet nesting (Canadian Marbled Murrelet Recovery Team 2003), and inclusion of younger forests would simply support age-driven structural differences (Waterhouse et al. 2002, 2007, 2008);
2. re-assess habitat attributes of murrelet nest sites in Mussel Inlet on the central mainland coast using the nest sample of Kaiser and Keddie (1999) and two additional nest sites located in 1992 (Burns et al. 1992) from the same study area; and
3. evaluate these findings in the context of management planning on the Central Coast.

STUDY AREA

The 39 478-ha study area is located on the Central Coast of British Columbia and overlaps Mussel Inlet (52° 54' N, 128° 05' W; Figure 1). It is made up of portions of the Sheep Passage (16,693 ha), Kynoch (14 556 ha), and Kitlope (400 ha) Landscape Units (British Columbia Integrated Land Management Bureau 2009b). Mussel Inlet is topographically complex. It is a steep-walled fjord with narrow river valleys and large areas of patchy alpine forest that occur among avalanche chutes and rocky outcrops (Kaiser and Keddie 1999). Western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and amabilis fir (*Abies amabilis*) trees dominate the Coastal Western Hemlock Very Wet Maritime (CWHvm1 and vm2) biogeoclimatic variants, which generally occur below 700 m. Above 700 m to approximately 1000 m, mountain hemlock (*Tsuga mertensiana*), yellow-cedar (*Chamaecyparis nootkatensis*), and amabilis fir trees are found in the Mountain Hemlock Moist Maritime (MHmm1) biogeoclimatic variant (for descriptions, see Meidinger and Pojar 1991; Green and Klinka 1994). Although the Mussel Inlet area is relatively undisturbed by resource extraction, some single-tree harvesting and targeting of estuaries of river valleys for redcedar occurred within 2 km of the inlet approximately 40 years before the radio-telemetry studies of Burns et al. (1992) and Kaiser and Keddie (1999).

METHODS

Sampling Design

Our sample included potential nest sites located by tracking radio-tagged birds (Burns et al. 1992; Kaiser and Keddie 1999). Of five radio-tagged breeding birds in 1992 (from a total of seven individuals captured), four showed 24-hr incubation cycles, and of these four, one bird was not detected inland, one radio was found stationary, suggesting its detachment (or predation of the bird), and two birds were tracked inland to potential nest sites. Kaiser and Keddie (1999) established that 24 (in 18 pairs) of 55 murrelets with attached radio transmitters showed 24-hr incubation cycles, and tracked 16 of these

individuals (including four pairs) to 12 potential nest sites. Photography of the 1999 potential nest sites is available through Simon Fraser University (2003).

For both projects, potential nest sites were confirmed by triangulation from a helicopter to within 100 m of the radio transmitters on the incubating birds, but nests were not visually confirmed due to limited ground access in the steep terrain. Three nest sites were located outside of mature/old forest according to the Vegetation Resources Inventory (VRI) mapping layer (GeoBC 2009), but two of these sites (N5 and N8) did contain mature/old forest within the 100-m buffer (i.e., the intended sample unit being a 100-m radius, 3-ha plot). We considered all the reported 1992 and 1999 potential nest sites for this study, but excluded two of the 14 from some or all analyses, as follows (Table 1):

- N5 was obscured by shadow on the air photos; therefore, it was used only when information could be taken from existing databases (i.e., 2008 habitat map).
- N12 was excluded from all analyses because it occurred in a non-forested polygon at 800 m (therefore, by definition it would be classed Nil for habitat quality) and was likely a ground nest. Also, the tagged bird at N12 had had a damaged foot; therefore, its site selection for a ground nest location may have been due to this physical constraint rather than to a preferred habitat choice (Kaiser and Keddie 1999).

TABLE 1 *Descriptions of probable nest sites by year and capture date in Mussel Inlet. Based on the original reports of Burns et al. (1992) and Kaiser and Keddie (1999), respectively. Attributes of nest sites, including elevation, tree species of the forest stand with the nest site, and presence of mossy platforms are taken from the original reported descriptions.*

Nest	Year	Capture date	Elevation (m)	Tree species[a]	Reported potential mossy platforms[b]
N1	1999	30 May/24 June	400	SsHwBa	No
N2	1999	25 May/23 June	215	SsCw(HwDr)	Yes
N3	1999	30 May/7 June	245	HwCw(SsBa)	—
N4	1999	26 May/10 July	620	HwCw	No
N5[c]	1999	25 May/24 June	490	CwHw(Hm)	Yes
N6	1999	1 June/12 July	400	CwHwSs(Ba)	—
N7	1999	1 June/22 June	310	Cw(BaHwDr)	—
N8	1999	31 May/9 June	490	CwHm(Hw)	—
N9	1999	1 June/23 June	185	BaHw(Cw)	Yes
N10	1999	31 May/22 June	230	SsHw(BaCw)	Yes
N11	1999	1 June/23 June	110	Cw(HwSs)	Yes
N12[d]	1999	25 May/15 June	800	Willow/sedge	No
N13	1992	25 May /2 June	80	Cw	Yes
N14	1992	30 May/5 June	400	Hw(Ba)	Yes

a Forest cover polygons based on leading species (see Resources Inventory Committee 2002). Definitions for tree species: Ss = *Picea sitchensis*; Hw = *Tsuga heterophylla*; Ba = *Abies amabilis*; Dr = *Alnus rubra*; Cw = *Thuja plicata*; Hm = *Tsuga mertensiana*

b Interpreted from descriptive comments of nest sites made by Kaiser and Keddie (1999) or Burns et al. (1992) from a helicopter. A blank indicates that no information was provided in the description to indicate presence or absence of platforms.

c Excluded from most analyses due to poor photography.

d Excluded as non-forest; therefore, classification by definition is Nil habitat. Because the bird had an injured foot, we cannot attribute site selection to preferred habitat choice.

We defined the study area (Figure 1) for random sampling as the area within the perimeter of the cluster of nest sites plus a 5-km external buffer (see Zharikov et al. 2006; Waterhouse et al. 2007, 2008). The study area boundaries were adjusted to within the height of the surrounding adjacent mountains as a closed catchment area; thus, we assumed that the murrelets were not flying over the ridges into other drainages.

For random sampling, we used a two-step process to ensure that random points could occur in similar locations to nests N5 and N8 that fell outside of

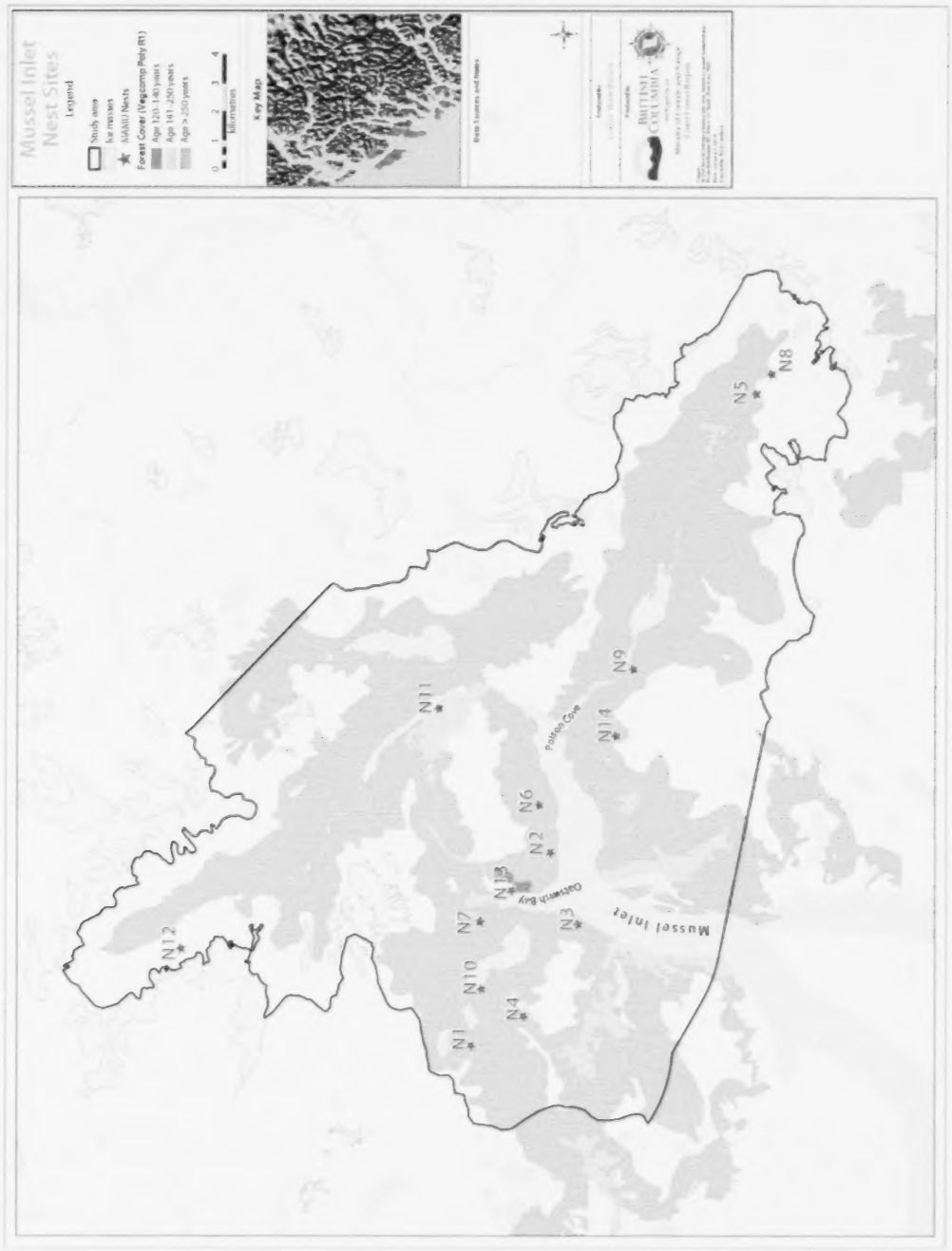

FIGURE 1 *Study area showing mature (light green)/old (dark green) forest > 140 years old based on Vegetation Resource Inventory mapping (GeoBC 2009) and location of 14 potential nest sites relative to mature/old forest.*

the boundary of the mature/old VRI mapped forest cover. First, we generated 194 non-overlapping random points within the study area. Next, using the VRI map layer (GeoBC 2009) and air photos, we confirmed that the random points had mature/old forest within 100 m of the centre point. We found that only a subset of 30 points contained mature/old forest. The remaining 164 random points were located either within alpine areas (66%), forest younger than 140 years old (22%), or lake (< 1%), or could not be interpreted due to poor visuals on the photo image (11%). Furthermore, 27% of these 164 points had been within mature/old forest according to the VRI map, but for this project were classed as alpine or younger forest when directly interpreted on the air photos. Of the final subset of 30 random points, three pairs of points were > 200 m but < 600 m apart. Therefore, we randomly eliminated one of each pair to be consistent with earlier studies and to space points at least 600 m apart (this was originally done to enable use of non-overlapping 300-m or 100-m radius plots around the point to describe habitat [Waterhouse et al. 2004, 2008]).

Habitat Assessment

The air photo interpreter (A. Donaldson) assessed habitat attributes and habitat quality class (Table 2) by centring the 3-ha plot on each nest site or random point (hereafter referred to as nest plot or random plot, respectively).

TABLE 2 *Habitat attributes described using air photo interpretation method. Adapted from Donaldson (2004) and Waterhouse et al. (2004)*

Variable	Variable classes and definitions of classes
Air photo habitat quality	• **Very High**: forest > 28 m tall and ≥ 250 years old; abundant large trees and large crowns; excellent canopy structure; best habitat in study area • **High**: forest > 28 m tall and ≥ 250 years old; common and widespread large trees; very good canopy structure • **Moderate**: forest usually 19.5–28 m tall and forest > 140 years old; large trees with good crowns present but patchy distribution • **Low**: forest generally > 19.5 m tall or forest > 140 years old; patchy and sparse large trees; poor canopy structure • **Very Low**: forest generally < 140 years old and/or trees < 19.5 m tall; large trees and complex canopy structure are sparse or absent • **Nil**: non-forested; all key habitat features absent
Forest cover > 140 years old[a]	• Proportion (%) of plot with forest > 140 years old thought to provide potential nesting habitat. We inferred that if plots have < 100% cover the nest site was closer to an edge.
Forest cover ≤ 140 years old[a]	• Proportion (%) of plot with forest ≤ 140 years old, excluding non-vegetated and vegetated but non-treed portions of plot. We inferred edges resulting from disturbance (e.g., clearcut or fire) from this variable.
Non-vegetated cover[a]	• Proportion (%) of plot non-vegetated and non-treed. We inferred natural edge owing to topography (e.g., rock outcrop) from this variable.
Vegetated cover[a]	• Proportion (%) of plot vegetated but non-treed. We inferred natural edge owing to disturbance or topography (e.g., avalanche chute) from this variable.
Tree height	• Average estimated height (m) of the dominant, co-dominant, and high intermediate trees for the upper tree layer (Resources Inventory Committee 2002)
Large trees	Dominant trees with large crowns ≥ 5 m above the canopy of the main stand • **Prevalent**: > 20% of stems are above the main canopy • **Sporadic**: 3–20% of stems are above the main canopy • **None**: < 3% of stems are above the main canopy

continued

TABLE 2 *continued*

Variable	Variable classes and definitions of classes
Canopy complexity	Estimate of overall variability of canopy structure and the distribution and abundance of large crowns and canopy gaps created by local topography (e.g., slope, hummock, and streams), vertical complexity, and/or past stand disturbance • **High**: well-distributed large crowns and canopy gaps creating a heterogeneous horizontal layer; optimum crown closure typically 40–60% • **Moderate**: fewer scattered large crowns. Varying numbers of canopy gaps, either well-distributed or clumped, which result in greater variability in crown closures—typical range is 30–70% • **Low**: few or poorly distributed visible large crowns and closed forest with few canopy gaps (usually high crown closure), or few large crowns but forest predominantly open (gappy, usually low crown closure)
Vertical complexity	Describes uniformity of the forest canopy by considering estimates of the total difference in height of leading species and average tree layer height and gappiness. Three classes applied to the sample (Resources Inventory Committee 2002): • **Uniform**: 11–20% height difference • **Moderately Uniform**: 21–30% height difference • **Non-uniform**: 31–40% height difference
Large gaps	Significantly visible openings (≥ 1 tree length wide) within the canopy • **Prevalent**: occupies > 20% of plot • **Sparse**: occupies 5–20% of plot • **None**: occupies < 5% of plot
Small gaps	Smaller openings (< 1 tree length wide) within the canopy • **Sporadic**: gaps usually occupy 5–40% of plot • **Prevalent**: gaps usually occupy > 40% of plot
Crown closure	Percent estimate of the vertical projection of tree crowns (upper layer) upon the ground (Resources Inventory Committee 2002)
Meso slope	Relative position of plot within the local catchment area (~30 to 300 m vertical difference [Luttmerding et al. 1990]) • **Low**: lower slope includes toe and flat • **Mid**: mid slope • **Upper**: upper slope (includes ridge tops)

a From a measurement perspective, some of the cover variables are not independent because their composition must sum to 100%. However, we opted to treat them as independent because transformations would complicate their interpretation, and our intention is to evaluate their individual impact.

The size of these plots was intended to capture the uncertainty of the nest site location, where sites were estimated to be within 100 m of the "true" location (Waterhouse et al. 2004). A plot represents habitat for the murrelet at the patch scale by describing the forest structure closely associated with and likely influencing the nest tree (Waterhouse et al. 2008).

We further examined the habitat quality class of plots using the 2008 habitat map (Figure 2). This map was produced after the selection of the random plots for this project; thus, it was not available to guide plot placement into individual polygons of a single habitat class. Although the air photo habitat classification used to derive the map was the same as the one used by the air photo interpreter to directly assess the plots, the class assigned by directly assessing a plot could differ from that obtained by overlaying the plot on the 2008 habitat map for two reasons. First, the plot value could differ from the polygon value if the mapped polygon represented a larger area into which the

FIGURE 2 *Study area overlaid with 2008 habitat map produced for ecosystem-based management for the B.C. Ministry of Environment (Donaldson and Smart 2009a, 2009b; Donald et al. 2010). Red is Nil and Blue represents Very Low to Very High habitat classes. The Figure 1 VRI mature/old forest map is also overlaid (yellow lines) to show similarities (blue area with yellow slashed lines) and differences in mapped potential habitat (red area with yellow slashed lines) between the different map layers.*

plot fell and the plot attributes had been averaged into the larger polygon (Waterhouse et al. 2007, 2008). Second, if a nest site or random point was near the border of a polygon on the 2008 habitat map, the plot could potentially intersect two or more polygons that were classed differently for habitat quality on the map. In the latter case, for examining selectivity, we assigned the plot the dominant habitat class, which we defined as the class covering the largest portion (greatest percent cover) of the plot. We assumed that this would be the most likely class assigned had the polygons been averaged within the plot.

Analyses

We tested for differences between habitat attributes and habitat quality of nest plots and random plots using non-parametric Wilcoxon signed rank (W+) tests for continuous (including percentages) and ordinal variables in JMP 7.0.2 (SAS 2008); the latter tests are only approximate. Random plots represent habitat available to the bird but not necessarily unused habitat; hence,

if the values of habitat attributes of nest plots differed significantly from those available based on the random sample, we considered murrelets as potentially selecting for (or against) that habitat type (Manly et al. 2002). For ordinal variables, potential selectivity would be indicated by use in higher proportions than available and avoidance by use in lower proportions than available with availability represented by the random sample. Our level of significance was $\alpha \leq 0.10$, where due to the small sample and the murrelet being a species at risk (British Columbia Ministry of Water, Land and Air Protection 2004), we decided to err on the side of identifying potential false differences. Our sample of nests was too small to statistically test for differences for nominal variables among variable categories.

RESULTS

Habitat Availability within the Study Area

Approximately half (55%) of the 39 078-ha study area included mature/old forest based on the VRI map (Figure 1). Mature/old forest occurred up to a maximum elevation of 1500 m with approximately 28% above 700 m. Overall, on the 2008 habitat map, only small areas of the study area were classed as Low (3%), Moderate (4%), and High/Very High (combined 1%) for habitat quality. Instead, the area was classed mostly as Nil (61%) or Very Low (31%). Very Low quality habitat included 190 ha of forest <140 years old according to the projected VRI.

A coarse visual comparison of total suitable nesting habitat between the VRI map (Figure 1) and the 2008 habitat map (Figure 2) suggested that approximately 6000 ha (28%) of the 21 343 ha VRI mature/old was classed as Nil (i.e., non-forested) on the 2008 habitat map. The over-projection of mature/old forest for VRI more likely occurred at higher elevations, although we were unable to make this direct comparison with our data sources.

Habitat Attributes of Nest Plots

Differences in the average elevation between nest and random plots were not statistically significant (Table 3), and elevational ranges were similar. For example, for nest plots (n = 12), elevation ranged from 80 to 620 m, and for random plots (n = 27), elevation ranged from 24 to 615 m. On the air photos, nest plots were generally characterized as having some large trees and mod-

TABLE 3 *Mean values (standard error) and non-parametric Wilcoxon signed rank (W_+) tests for continuous variables, comparing nest plots with randomly located forest plots showing possible significance for forest cover >140 years old, forest cover ≤140 years old, and crown closure*

Variable	Nest (n = 12)	Random (n = 27)	W+ (P)
Elevation (m)	307 (46)	271 (28)	0.61 (0.54)
Forest cover >140 years old (%)	77.5 (6.8)	59.4 (5.4)	1.86 (0.06)
Forest cover ≤ 140 years old (%)	7.5 (5.1)	16.6 (4.1)	-1.81 (0.07)
Vegetated cover (%)	6.7 (4.7)	11.7 (4.1)	-0.77 (0.44)
Non-vegetated cover (%)	8.3 (4.4)	8.7 (2.0)	-0.67 (0.50)
Crown closure (%)	44.2 (3.4)	50.6 (1.9)	-1.62 (0.10)
Tree height (m)	23.9 (1.0)	23.3 (0.8)	0.55 (0.58)

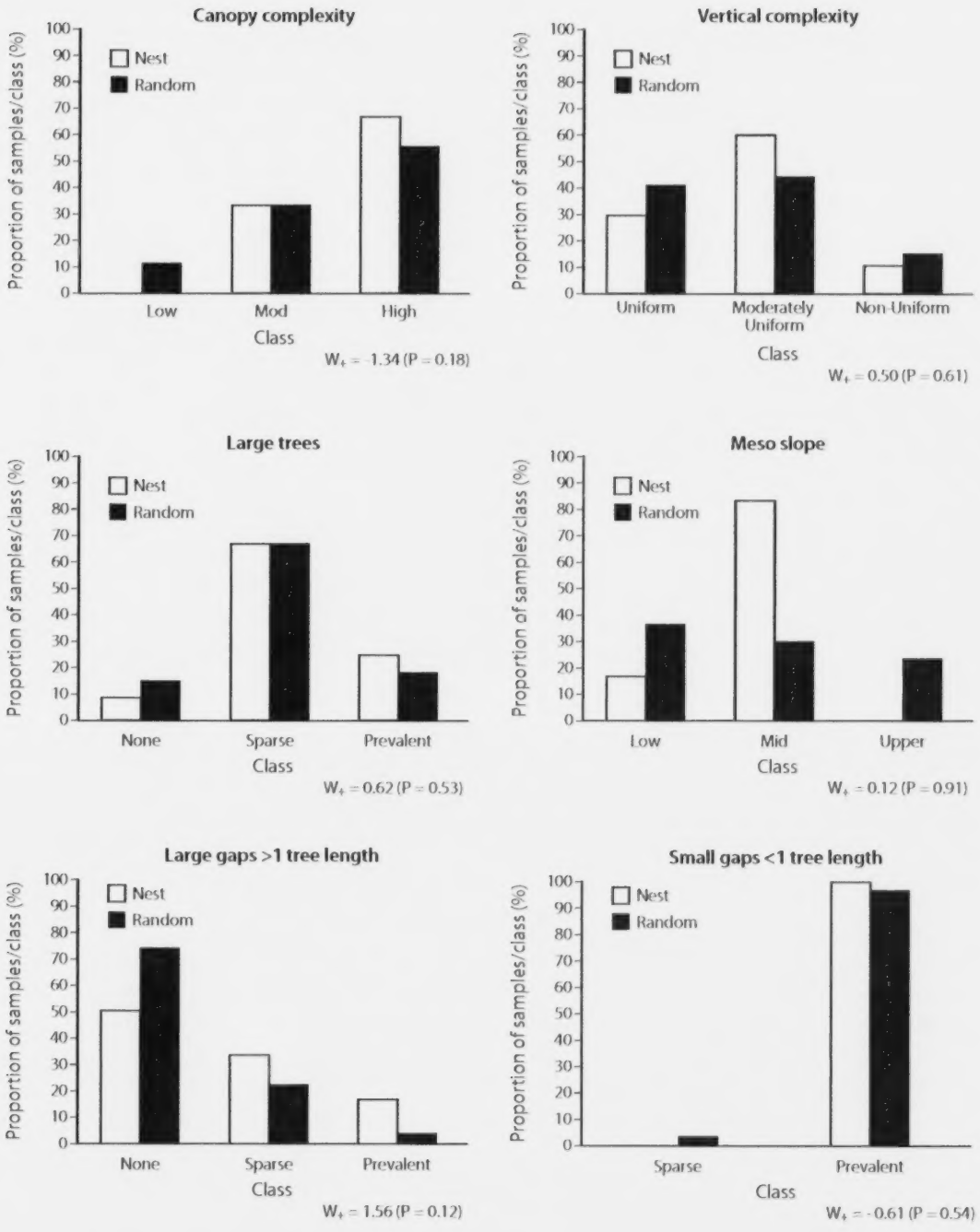

FIGURE 3 *Proportion of nest (n = 12) and random (n = 27) plots distributed by class for canopy complexity, vertical complexity, large trees, meso slope, large gaps, and small gaps. Included are non-parametric Wilcoxon signed rank tests W+ (P) between nest and random plots.*

erate to high canopy complexity, while occurring in low to mid meso slope positions (Figure 3). Yet there were few significant detectable differences between nest plots and random plots (Table 3; Figure 3). Exceptions were that nest plots compared to random plots had significantly more forest cover >140 years old ($P = 0.06$; Table 3) and significantly less forest cover ≤140 years old ($P = 0.07$; Table 3). The forest of nest plots compared to random plots had significantly lower crown closures ($P = 0.10$; Table 3).

Habitat Quality of Nest Plots

Habitat quality of nest and random plots, directly interpreted from the air photos, did not significantly differ, although Figure 4 indicates the potential for higher proportional use of Moderate and Low habitats and lower proportional use of the Very Low habitats by nesting murrelets. By definition and by using direct assessment on air photos, neither nest nor random plots could be classed as Nil because all would have some mature/old forest. The comparison between dominant habitat quality of nest and random plots based on the 2008 habitat map was also non-significant but indicated a similar trend for higher proportional use of Moderate and Low habitats and lower proportional use of Very Low habitat by murrelets (Figure 5). For this latter comparison, the nest sample ($n = 13$) included N5 because it was within a Very Low polygon on the 2008 habitat map. Some nest and random plots were classed as Nil based on the 2008 habitat map (Figure 5). Nest plots lacked Very High and High habitats using direct interpretation and the 2008 habitat map, and only one random plot was classed as High.

Habitat class assigned to the same plots by the two different approaches (direct interpretation of habitat quality compared to overlay with the 2008 habitat map for dominant habitat quality) differed for 59% of the 39 individual plots (Table 4). Most (91%) of the 23 plots that differed by class were classed lower on the 2008 habitat map than by the direct air photo assessment (Table 4). Four plots that were classed as Nil based on dominant habitat quality on the 2008 habitat map were classed Very Low by direct interpretation.

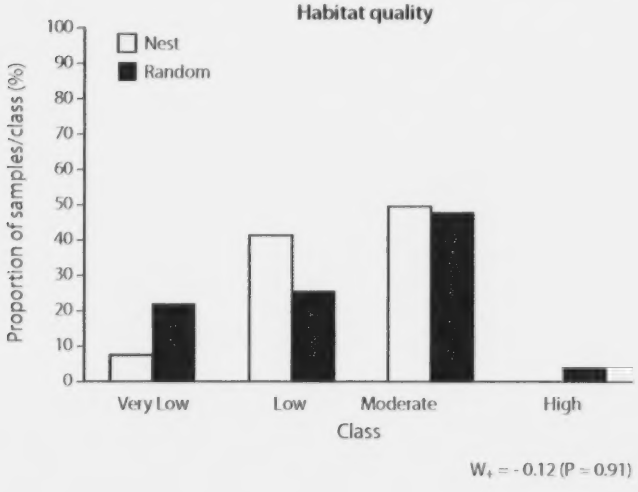

FIGURE 4 *Proportion of nest (n = 12) and random (n = 27) plots distributed by class for habitat quality within forest in the >140-year-old layer. Included is the non-parametric Wilcoxon signed rank tests W+ (P) between nest and random plots.*

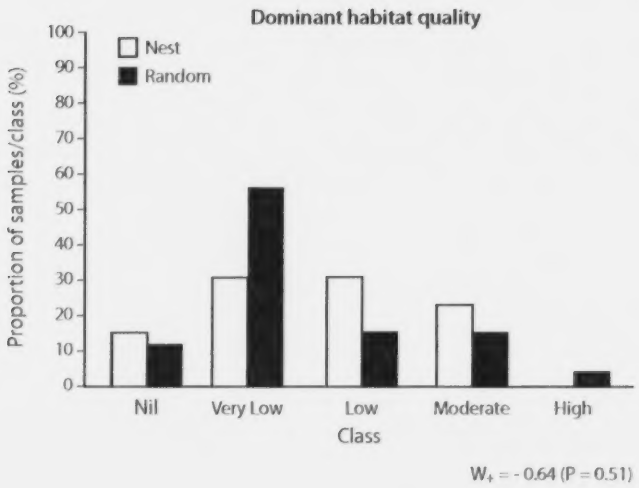

FIGURE 5 *Proportion of nest (n = 13) and random (n = 27) plots based on dominant habitat quality class of the plot from the 2008 habitat map (Donaldson and Smart 2009a, 2009b). Included is the non-parametric Wilcoxon signed rank tests W+ (P) between nest (white) and random (black) plots.*

TABLE 4 *Comparison of habitat quality classes assigned to plots from direct air photo interpretation with those obtained from the 2008 habitat map. The numbers shown are sites in each category (n = 39, nest and random sites pooled). Numbers in bold type show the sites assigned identically by both methods. Nil sites were eliminated from the direct assessment sample; thus, comparisons cannot be made between the 2008 habitat map and direct interpretation for it. Overall, more plots on the 2008 habitat map were classed lower compared to those same plots classed by direct interpretation.*

		Air photo habitat quality from 2008 habitat map				
		High	**Moderate**	**Low**	**Very Low**	**Nil**
Direct air photo interpretation of habitat quality	High	**0**	1	0	0	0
	Moderate	1	**6**	2	7	3
	Low	0	0	**5**	7	0
	Very Low	0	0	1	**5**	1
	Nil	NA	NA	NA	NA	NA

Habitat Interpretation Comparing Old to New Photography

Estimated habitat parameters (tree height, stand age, crown closure, and vertical complexity) of nest plots using the finer resolution and colour 1:15 000 air photos did not substantially alter descriptions based on the 1:40 000 black-and-white photos used by Waterhouse et al. (2004) (Table 5). Habitat quality could not be directly compared because the classification itself had changed subsequent to Waterhouse et al. (2004) from a 5-rank classification to a 6-rank classification, although similar to the 2004 1:40 000 photo analysis, this analysis did not classify any nest plots as High or Very High.

TABLE 5 *Proportions of nest plots by habitat attribute class compared from the two sets of air photos used by Waterhouse et al. (2004) and for this study*

Variable	Black-and-white 1:40 000 (%; $n = 8$)	Colour 1:15 000 (%; $n = 12$)
Tree height (m)		
<20	25.0	17.0
20–28	62.5	83.0
29–32	12.5	0.0
Age (yrs)		
141–250	37.5	42.0
>250	62.5	58.0
Crown closure		
<26%	12.5	0.0
26–35%	12.5	25.0
36–65%	75.0	75.0
Vertical complexity		
Uniform	37.5	25.0
Moderately uniform	50.0	67.0
Non-uniform	12.5	8.0

DISCUSSION

Defining Habitat Availability

Understanding murrelet nesting habitat in the context of the Mussel Inlet study area proved challenging in part due to the limitations in sample size and to the difficulty in determining and sampling random habitat availability using the VRI map (GeoBC 2009). Our sample of nests was small, and locations could not be ground-truthed but instead relied on GPS co-ordinates derived using triangulation from a helicopter combined with visual confirmation on air photos by the field personnel. If nest locations were inaccurate due to location error of the radio-tagged murrelet or the underlying maps, then our results would be unreliable (Gantz et al. 2006; Visscher 2006). We used a 100-m buffer to help account for potential uncertainty of the nest location in describing average habitat condition of the nest plot (Waterhouse et al. 2002; see discussion in Gantz et al. 2006). More sampling in central and northern British Columbia will be needed to resolve whether habitat described by this sample from Mussel Inlet was representative of nesting habitat in topographically complex areas such as Mussel Inlet. Recent research (2006–2008) conducted in Port Snettisham, southeast Alaska, used a radio-tagged sample of murrelets, and located 37 separate nest sites (16 tree nests, 18 rock cliff or steep ground nests, and 3 nests for which habitat type could not be determined), including two in Canada on the Whiting River (1 tree and 1 cliff), which were located in topographically rugged unharvested areas (Barbaree et al. unpublished[1]; B. Barbaree, pers comm.[2]).

1 Barbaree, B.A., S.K. Nelson, B.D. Dugger, and S.H. Newman. 2010. Breeding ecology of Marbled Murrelets in Port Snettisham, southeast Alaska. Poster World Seabird Conference, September 7–11, 2010 www.worldseabirdconference.com/main.cfm?cid=1813&nid=14733.

2 Barbaree, B.A., Oregon State University, Nov. 30, 2010.

The problem in defining habitat availability was due to the likely overrepresentation of the amount of available mature/old forest on the VRI map that we found when we directly checked the randomly generated plots on the air photos (see Methods) and when we overlaid the VRI map with the 2008 habitat map (see Results, Figure 2). We were also challenged to randomly sample locations similar to those of the nest sites that bordered the mature/old forest polygon boundaries, and thus applied a two-step selection process that produced a subset of random points.

Although unlikely, we cannot preclude the possibility that the selected subset of random points could be biased, thereby misrepresenting random availability. For example, we were unable to test whether the final set of random points represented the elevational gradient because our estimates of the amount of mature/old forest would be based on the VRI map, which potentially overrepresented the amount of mature/old forest. Yet elevation affects habitat attributes that were interpreted to estimate habitat quality, such as tree height (e.g., see Waterhouse et al. 2008). In this example, if lower-elevation random points with larger and taller trees were overrepresented compared to higher-elevation points with smaller and shorter trees, then a biased estimate of availability could incorrectly show a lack of selectivity or selectivity for poorer-quality habitats by the murrelet. For this study, because the random locations were limited to within the 0–700 m elevational stratum, habitat selectivity results can be extrapolated only to this lower-elevation band. Selectivity by murrelets for particular elevations was not supported within this band.

Habitat Attributes of Nest Plots

Despite potential problems with both the nest and random samples, we identified some commonalities and differences between the classifications of habitat attributes for the Mussel Inlet nest plots and those from other studies on Haida Gwaii (Waterhouse et al. 2007) and the South Coast of British Columbia, including areas on the Sunshine Coast and west Vancouver Island (Waterhouse et al. 2008). Similar to these other coastal studies, nest plots in Mussel Inlet tended to have some large trees, moderate to high canopy complexity, and moderately uniform vertical complexity, and did not occur on upper meso slopes. Yet, average tree height of nest plots, estimated from air photos, was shorter in Mussel Inlet (~24 m; Table 3) by at least 5 m compared to those on Haida Gwaii (~32 m) and the South Coast (range ~29–34 m).

For murrelets, complex forests with large trees, as described by air photo attributes, are thought to provide nest platform structures and cover above the nest to reduce exposure to predators and inclement weather while providing accessibility to the nest (see Waterhouse et al. 2007, 2008). Presence of mossy nesting platforms at some of the nest plots is inferred from original descriptions made by observers in a helicopter (Table 1). Murrelets may avoid nesting on upper slopes (e.g., ridges) because of exposure to wind and because these stands are often more open and less productive, with smaller stunted trees (see Waterhouse et al. 2008, 2009). The lower average tree heights for Mussel Inlet compared to other areas suggest that air photo interpreters may need to use discretion, particularly as latitude increases along the coast, in interpreting the standards for classifying habitat quality by placing more emphasis on relative tree size and canopy structure rather than minimum tree height classes (Waterhouse et al. 2008). Of importance for fjordland-type areas, such as Mussel Inlet, is that the visibility of large trees

in gullies may be obscured on air photos. This observation was reported by Kaiser and Keddie (1999) based on their helicopter nest searches.

Murrelets in Mussel Inlet selected nest plots with significantly more forest cover >140 years old than in random plots (Table 3), in contrast to murrelets on the Sunshine Coast, which selected nest plots with significantly less forest cover of this age (Waterhouse et al. 2008). Yet, for both these study areas, average amounts of forest cover >140 years old at nest plots were approximately similar (~77%), while the average amounts for random plots differed: Sunshine Coast (~90%) compared to Mussel Inlet (59%). If murrelets locate nests to balance between the bird's need to access the stand while maintaining cover, as suggested by Waterhouse et al. (2008), then coast-wide differences in available forest for murrelets may differentially affect our interpretation of their selectivity as quantified using air photo attributes in different areas. On the South Coast, where forests appear denser and less gappy than Mussel Inlet, murrelets may have located nests near edges and openings to more easily access the mature/old forest matrix, which in turn resulted in nest plots having lower amounts of forest cover >140 years than did random plots (Waterhouse et al. 2008). In contrast, given the already accessible open and gappy forest in Mussel Inlet, murrelets may have located nests in areas with more forest cover >140 years old relative to random locations in seeking opportunities to find suitable nest platforms with cover (Figure 3). Although overall crown closure was significantly less at nest plots compared to random plots, the small difference in closure was likely due to the random plots being denser stands, as suggested by greater amounts of forest cover ≤140 years old (Table 3). Distinct coast-wide differences in forest structure thus influence interpretations of murrelet habitat selectivity because both availability and combinations of desirable structure likely vary in different landscapes. For example, Willson et al. (2010) describe an increasing frequency of marbled murrelet ground nesting (within and outside of forested areas) to the north and west of the species' distribution, and they attribute the shift to ground nesting as a means of exploiting access opportunities for takeoff and landing associated with streams in the rugged terrain (Willson et al. 2010).

Habitat Quality of Nest Plots

Based on the air photo habitat classification, we did not confirm selectivity of higher-quality habitats as found in the other coastal studies (Waterhouse et al. 2007, 2008). We attribute the inconclusive testing of the High/Very High classes to the low probability of finding a nest in this habitat due to the small samples of tagged birds (e.g., 1991: 2; 1999: 12) combined with the small proportion of the study area (1%) that was classed High/Very High. Many more birds likely nested in the Mussel Inlet area compared to the tagged sample because 400–600 birds were reported using Mussel Inlet at the same time as the telemetry projects were being conducted (Burns et al. 1992; Kaiser and Keddie 1999). If we underestimated the area of available habitat for murrelets by our assumptions, our results would likely be misleading (Burger et al. 2004b; Zharikov et al. 2006). Furthermore, if the sampled murrelets were less experienced or had constrained habitat choices as late nesters, habitat selectivity could also be difficult to detect (Waterhouse et al. 2008). The 1999 murrelets nested, on average, 3 weeks late compared to 1991/1992 breeding

birds (Kaiser and Keddie 1999), but this was likely due to a cold ocean year, with the average population nesting late (D. Bertram, pers. comm.[3]).

Figure 4 indicates a possible trend for higher proportional use of Moderate and Low habitats, which comprised 9% of the study area, and lower proportional use of the Very Low habitats, which comprised 31% of the study area. Thus, murrelets in Mussel Inlet may be selecting for higher-classed habitats from those available, but, with limited amounts of forest in these topographically complex watersheds, a large proportion of the population would need to use poorer-quality habitats as classed by air photo. For example, compared to 14% for the other coastal studies (Burger and Waterhouse 2009), 50% of nest plots in this study were classed as Low or Very Low for habitat quality. Availability of suitable higher-quality habitat may be further limited for murrelets because they are thought to space themselves and nest at low densities (reviewed in Burger and Waterhouse 2009). Murrelet densities (birds per ha of likely suitable forest habitat), using an estimated 500 birds for this study area (i.e., see previous paragraph), would range from 0.28 if birds were nesting only in habitats in the top three habitat classes to 0.16 for the top four habitat classes, and 0.032 for all five forested habitat classes. Based on the use of broad habitat definitions (mature and old, and > 28. 5 m tree height) and VRI maps for the entire Central Coast, Burger et al. (2004b) reported murrelet densities (birds per ha) from radar counts that ranged between 0.031 and 0.046. Results from more recent radar surveys (2006 and 2008) suggest that these estimates should be at least doubled (D. Bertram[4]). If doubled, then radar density estimates are more similar to the coarse estimate of 0.16 based on the use of the top four air photo habitat classes, and as such indirectly suggest that murrelets may be nesting in some lower-quality habitats as mapped using the air photo standards. If amount of habitat from the VRI map was overestimated (as we suspect for this study area but not necessarily for the entire Central Coast), then nesting densities reported by Burger et al. (2004b) could be even greater for this reason too.

An additional consideration discussed by Waterhouse et al. (2008) that applies to interpreting the selectivity results for Mussel Inlet is that the air photo habitat classification focusses on forest structure described at the habitat scales of patch and stand but does not account for multi-scale habitat selection (Orians and Wittenberger 1991) or influences that are external to forest structure, such as predators (Thomson 2006). For example, other research from the British Columbia South Coast suggests that murrelet nest site selectivity is influenced by configuration of the broader landscape (e.g., Zharikov et al. 2006), proximity of marine habitats for foraging (e.g., Barrett 2008), and individual nest structures (e.g., Manley 1999). The importance of how habitat selectivity by murrelets in Mussel Inlet, as interpreted on air photos at the patch scale, may vary with these factors is unknown.

Interpreting Air Photos

Changing air photo scale from 1:40 000 to 1:15 000 and image colour from black-and-white to colour did not appear to strongly affect the classification of attributes in this study. But changing the area of interpretation—that is,

3 D. Bertram, Marine Bird Conservation Biologist, Environment Canada, Science & Technology Branch, Wildlife Science Division, Institute of Ocean Sciences, January 17, 2011. Unpublished data.

4 D. Bertram, Marine Bird Conservation Biologist, Environment Canada, Science & Technology Branch, Wildlife Science Division, Institute of Ocean Sciences, January 17, 2011. Unpublished data.

polygon scale used to produce the 2008 habitat map compared to 3-ha plots for the research, thus resolution—did affect habitat classification. Scale issues have been identified in other studies where habitat quality of patches could be under- or over-estimated by averaging habitat quality across larger polygons (Waterhouse et al. 2007, 2009; Donald et al. 2010). Averaging habitat quality estimates over polygons can sometimes miss the presence of smaller, higher-quality nest patches (Waterhouse et al. 2009). Key for the Mussel Inlet area is that on the 2008 habitat map, some polygons likely contain higher-quality patches.

Management Implications

Our results indicate that using the air photo standards to classify potential murrelet nesting habitats in this fjordland-type of environment is appropriate to discriminate higher-quality habitats. Yet, an important consideration for management in the Mussel Inlet landscape, which has low amounts of higher-quality habitats, based on air photo interpretation, and large potential breeding populations, is that those higher-quality habitat classes considered to be "suitable" for managing murrelets may differ from those considered to be suitable in other landscapes. Typically, Very High, High, and Moderate habitats are targeted for spatial management (i.e., mapping management polygons; reviewed in Burger and Waterhouse 2009). Both the distribution of nest plots in Mussel Inlet among the habitat classes and the possible trend for selectivity for habitats classed as Moderate or Low suggests that for these atypical, topographically complex, fjordland-type areas, managers may need to consider expanding the suitable habitat definition to include habitats classed as Low if they occur at elevations below 700 m (e.g., Horn et al 2009; Donald et al. 2010). However, consistent with other studies, prioritizing retention of habitats in the Very High, High, and Moderate classes should not be forsaken because their importance was not adequately tested in this study due to the small sample of nests combined with uncertainty about nest locations and challenges in selecting a random sample. Ideally, in forest habitats classed as Moderate or Low by air photo interpretation, the presence of suitable trees and potential nest platforms should be confirmed through the use of low-level aerial surveys if these habitats are to be retained to meet murrelet management objectives (Donald et al. 2010).

Interpretations of murrelet habitat selectivity are sensitive to the resolution of interpretation. The visibility of platforms, as reported by the original researchers (Table 1), suggests that use of the aerial survey method (Burger et al. 2004a) to verify the indicated habitat potential based on air photo interpretation or to produce a more accurate fine-scale habitat map would likely improve habitat management in Mussel Inlet (Waterhouse et al. 2010). Aerial survey mapping, as all mapping techniques, is limited by mapping resolution, scale, and effort. For this study area, given its topographic complexity, application of aerial survey mapping at a more intense, fine scale would likely improve the air photo 2008 habitat map, thereby ensuring that small areas of high-quality habitat within lower-quality polygons or outside of forest polygons are not missed (Waterhouse et al. 2010).

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